State of the Art (SOTA)
Manual for Internal Combustion Engines

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Section 3.13

Table of Contents

3.13 STATE OF THE ART MANUAL FOR INTERNAL COMBUSTION ENGINES

3.13.1 SCOPE.

The state of the art (SOTA) performance levels discussed in this manual apply to all new stationary internal combustion (I.C.) engines with heat input rate greater than one million BTU per hour and for which a permit to construct and certificate to operate is required. The levels specify emission rates and control technologies applicable to the I.C. engines. The SOTA performance levels for emergency diesel generator engines, existing engines, two-cycle engines and engines combusting non-commercial fuel (such as landfill gas, digester gas, and refinery gas) will be determined on a case by case basis.

3.13.2. SOTA Performance Levels

The I.C. engines in general are classified by ignition of the fuel (spark ignited and compression ignited), operating cycle (two stroke and four stroke) and by air to fuel ratio and oxygen in the exhaust gas (lean burn and rich burn). In this manual, engines are classified by fuel type (natural gas, landfill gas, fuel oil, and diesel oil) and combustion characteristics (lean burn, rich burn). For any class of I.C. engines, recommended state of the art performance levels and control technologies are listed in the table below.

SOTA Performance Levels for Stationary Internal Combustion Engines

AIR CONTAMINANTS	EMISSION RATE (GRAMS/BHP-HR)	CONTROL TECHNOLOGY
Nitrogen Oxides	0.7	Combustion Control or Non Selective Catalytic Reduction or Selective Catalytic Reduction
Carbon Monoxide	0.5	Oxidation Catalyst
Volatile Organic Compounds	0.25	Oxidation Catalyst

Emissions of SO_2 and TSP/PM-10 are fuel dependent. No specific SOTA levels are specified at this time. Compliance with applicable rules will represent SOTA for emissions of SO_2 and TSP/PM-10.

3.13.3. Technical Basis

During the development of the SOTA performance levels, owners and operators of IC engines and equipment vendors were contacted to obtain information on emission rates and control technologies. Emission rates specified in the EPA's BACT/LAER clearing house of 126 facilities and permitted emission rates and stack test results of New Jersey facilities to whom a permit to construct and certificate to operate were issued in the last 5 years were reviewed.

Stationary IC engines are used in industrial applications requiring mechanical work in the form of shaft power, such as oil and gas production, construction, and electrical power generation. IC engines can operate on a variety of fuels at a wide range of speeds and with varying loads.

In an IC engine, combustion of a compressed fuel-air mixture is used to drive pistons in one or more cylinders with the linear reciprocating motion converted to rotary motion with a crankshaft. There are two basic types of reciprocating engines. Spark Ignited (SI) engines use a spark (across a spark plug) to ignite a compressed fuel-air mixture. Typical fuels for such engines are natural gas, gasoline, landfill gas and sewage or digester gas. Compression ignition (CI) engines compress air to a high pressure, heating the air to the ignition temperature of the fuel, which then is injected. Diesel fuel oil is normally used in CI engines, although some are dual fueled. Natural gas is compressed with the combustion air, and diesel oil is injected at the top of the compression stroke to initiate combustion in a dual fuel engine.

Reciprocating engines have either 4 stroke or 2 stroke operating cycles. Reciprocating engines are also classified based on air-to-fuel ratio and the exhaust oxygen content. Rich burn engines (which include 4 stroke SI engines) typically operate with an air-to-fuel ratio near stoichiometric and exhaust oxygen concentrations of one percent or less. Lean burn engines (which include 2 stroke SI engines and all CI engines) have lean (i.e. air enriched) air-to-fuel ratio and typical exhaust oxygen concentration of greater than one percent. Due to higher temperature and pressure in the C I engines, emissions of NOx, CO and Non-methane hydrocarbons are of concern. Available technologies to control emissions of these air contaminants are briefly described below.

3.13.3.1 Combustion Modification Strategies (Pollution Prevention)

<u>Air/Fuel Ratio Adjustment</u>

Lowering the air-to-fuel ratio in the rich burn engines limits oxygen availability in the cylinder, thus decreasing NOx emissions both by lowering peak flame temperature and by producing a reducing atmosphere. This technique is analogous to the use of low excess air in the boilers and process heaters and has limitation of producing excess CO and hydrocarbon emissions at very low air-to-fuel ratios. In addition to simple adjustment of the air-to-fuel ratio, it requires the installation of a feedback controller so that changes in load and other operating conditions may be followed.

In lean burn engines, increasing the air to fuel ratio decreases the NOx emissions. Extra air dilutes the combustion gases, thus lowering peak flame temperature and reducing thermal NOx formation. In order to avoid an engine derate, air flow to the engine must be increased at constant fuel flow, with the result that installation of a turbocharger (or modification of an existing one) is necessary to implement this technique. An automatic A/F controller also will be required for variable load operation. Air-to-fuel ratio adjustment is generally applicable to lean-burn engines, although space constraints may limit the extent to which turbocharger capacity may be increased. This control method is most effective on fuel-injected engines. carbureted engines do not have same A/F in each cylinder, with the result that changes in this ratio are limited.

Ignition Timing Retard

This adjustment lowers NOx emissions by moving the ignition event to later in the power stroke, when the piston has begun moving downward. Because the combustion chamber volume is not at its minimum, the peak flame temperature will be reduced, thus reducing thermal NOx formation. Ignition timing retard is applicable to all engines. It is implemented in spark ignition engines by changing the timing of the spark, and in compression ignition engines by changing the timing of the fuel injection.

Prestratified Charge

It is a technology for injecting fuel and air into the intake manifold in distinct "slugs" which become separate fuel and air layers upon intake into the cylinders. This creates a fuel rich, easily ignitable mixture around the spark plug, but an overall fuel lean mixture in the combustion chamber. Combustion occurs at a lower temperature, hence producing much less thermal NOx but without misfire even as the lower flammability limit is approached. Prestratified charge may increase CO and hydrocarbon emissions.

Low Emission Combustion

This is combustion of a very fuel lean mixture. A fuel lean mixture lowers cylinder temperatures and lowers NOx formation. This technology is not effective on diesel engines but does work for dual fuel engines, lean burn engines and rich burn engines.

3.13.3.2 Add on Controls

Non-Selective Catalytic Reduction (NSCR)

This technology uses three-way catalysts to promote the reduction of NOx to nitrogen and water. CO and hydrocarbons are simultaneously oxidized to carbon dioxide and water. NSCR is applicable only to rich burn engines (i.e. those with exhaust oxygen concentration below about one percent). Lean burn engine exhaust will contain insufficient CO and hydrocarbons for the reduction of the NOx present. NSCR retrofits, in addition to the catalysts and catalysts housing, require installation of an oxygen sensor and feedback controller to maintain an appropriate air to fuel ratio under variable load conditions.

Selective Catalytic Reduction (SCR)

SCR uses catalyzed reduction of NOx with injected ammonia. This technology is applicable to lean burn engines only. (i.e. those with greater than about one percent exhaust oxygen, as oxygen is a reagent in the selective reduction reaction). Retrofitting SCR involves installation of the reactor and catalyst, appropriate duct work, an ammonia storage and distribution system and a control system for variable load operation. SCR may result in ammonia slip and controls may be necessary for precise control of ammonia injection.

Electrification

This involves replacement of an IC engine with an electric motor.

The applicant may refer to documents listed in the reference section of this manual for additional details on air pollution control technologies.

3.13.4 Recommended Review Schedule

The next scheduled date for review of the performance levels specified in this manual will be December 1998.

3.13.5 References

1. USEPA, Office of Air Quality Planning and Standards. July 1993. *Alternative Control Techniques Document: NOx Emissions from Stationary Reciprocating Internal Combustion Engines.*

2. STAPPA/ALAPCO. May 1994. *NOx Control Options Guidebook*.

3. STAPPA/ALAPCO. May 1991. *Air Quality Permits, A Handbook for Regulators and Industry, Volume I*

4. USEPA. April 1993. *Compilation of Air Pollutant Emission Factors, Volume 1,Chapter 3 and 4, Gasoline and diesel Industrial Engines and Large Stationary Diesel and Duel fuel Engines*

5. NJDEP Permit Files

6. NJDEP Stack Emission Test Report Files

7. USEPA BACT/LAER Clearinghouse